

SAVANNAH RIVER NATIONAL LABORATORY

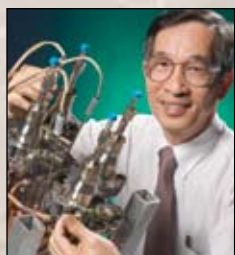
SCIENCE AT WORK



Storing Hydrogen for the Vehicle of the Future

SRNL at the forefront of hydrogen storage R&D

Also in this issue:



***Next-Generation
Hydrogen Isotope
Separation Process***



***Tailoring Inorganic
Sorbents for Strontium
and Actinides***

SRNL Designated DOE-Environmental Management Corporate Laboratory

On the Cover

This artist's conception of a hydrogen-fueled vehicle of the future illustrates how advances in hydrogen storage technology can make hydrogen-fueled vehicles a practical reality. SRNL has several R&D programs that draw on decades-long experience in handling hydrogen.



About Science At Work

SCIENCE AT WORK is the flagship publication of the Savannah River National Laboratory (SRNL). It is designed to provide our Department of Energy customer, members of the scientific community, and the general public highlights of SRNL programs to put science to work in high-value R&D to serve urgent national needs.

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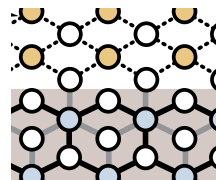
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From the Laboratory Director

*It is with great pride that we inaugurate the first issue of the Savannah River National Laboratory's magazine, **SCIENCE AT WORK**. For decades, this laboratory ... under its former names: Savannah River Laboratory and Savannah River Technology Center ... has been quietly serving the U.S. Department of Energy, DOE's Savannah River Site, and other customers by developing and deploying technology solutions that address real-world needs. When, in 2004, the Secretary of Energy designated us as a National Laboratory, we knew that one of our new priorities would be to increase the ways we communicate the technical excellence that has been one of the laboratory's historical trademarks.*

Our new magazine is designed to provide the reader the opportunity to learn more about the many ways that SRNL puts science to work, safely conducting high-value research and development, and applying it to some of the nation's most urgent needs.

We have organized the magazine to highlight work in each of our three major program areas: environmental management, energy security, and national and homeland security, along with brief articles on significant achievements and activities. Since SRNL's designation as the DOE Office of Environmental Management's "Corporate Laboratory" (see following article), our work to help to reduce technical uncertainties in order to assist DOE sites in meeting cleanup requirements has gained special significance that will be reflected here.

*Enjoy the first issue of **SCIENCE AT WORK**!*

A handwritten signature in blue ink, appearing to read "G. Todd Wright".

Dr. G. Todd Wright
Laboratory Director
Savannah River National Laboratory

We Put Science To Work™

SRNL Designated DOE-EM “Corporate Laboratory”

In early 2006, the U.S. Department of Energy (DOE) designated SRNL as the “Corporate Laboratory” for the DOE Office of Environmental Management (EM), recognizing SRNL as a key resource for EM and its programs at sites around the country. This designation also gives SRNL a new mandate to provide targeted technical assistance and technology solutions for cleanup efforts. In this role, SRNL will use its applied research leadership and a collaborative approach to assist DOE sites in enhancing cleanup, achieving cost efficiencies, and increasing safety by reducing technical risk.

EM’s mission is the accelerated risk reduction and cleanup of the environmental legacy of the nation’s nuclear weapons program and includes responsibility for the cleanup of 114 sites across the country. These tasks are technically complex and require innovation and advanced technologies to succeed. In particular, applied research is needed to enhance projects to stabilize high-level radioactive waste, clean up groundwater and soils, deactivate and decommission

EM Office of Environmental Management

safety ❖ performance ❖ cleanup ❖ closure

legacy facilities, and stabilize and dispose of transuranic and spent fuel wastes.

“For many years, SRNL has enabled the Savannah River Site to be one of the leading sites in the country in the areas of environmental cleanup and waste treatment and disposal, and we have also assisted other sites

throughout the complex by providing them with innovative technology solutions,” says Dr. G. Todd Wright, SRNL Laboratory Director. “It is a natural evolution for SRNL to take on this larger role of EM Corporate Laboratory in view of our proven performance and track record in EM, and our tradition of working well



As EM’s Corporate Laboratory, SRNL created an exhibit for the lobby of DOE’s Washington, D.C., headquarters (left) highlighting how EM uses science and technology to achieve its mission, with an emphasis on the role of SRNL and the other National Laboratories. The exhibit was presented to Secretary of Energy Samuel Bodman (center) by Dr. G. Todd Wright (left), Deputy Assistant Secretary Mark Gilbertson (right), and Assistant Secretary James Rispoli (above), with Robert Edwards and Bill Spader (background) of DOE-Savannah River.

with other National Laboratories to take advantage of complementary skills," he added.

Since the announcement, SRNL's leadership has been working closely with EM — particularly with Assistant Secretary for EM James A. Rispoli, Principal

Deputy Assistant Secretary for EM Charles E. Anderson, and Deputy Assistant Secretary for Engineering and Technology Mark Gilbertson — to plan SRNL's role as the EM Technology Integration Office. This role will extend over all the technical areas of the EM

program and integrate the best expertise of other DOE National Laboratories. Capabilities from universities and relevant industries will also be incorporated to deliver world-class services to support the EM customers. 🌐

SRNL's designation as EM's Corporate Laboratory builds on the laboratory's long history of helping sites throughout the Department of Energy complex by providing innovative technology solutions in radioactive waste management, environmental cleanup, and related challenges.



(a) Keith Hyde of SRNL (left) uses an innovative technology (Membrane Interface Probe) to delineate the depth discrete distribution of solvent in the subsurface sediment at the Waste Management Unit at DOE's Ashtabula Closure Project in Ohio.

(b) Keith Hyde of SRNL collects samples to measure hydrogen levels in groundwater from Mound's Operable Unit 1 in support of implementation of Monitored Natural Attenuation at the landfill in Ohio.



(c) Andy Foreman of SRNL performs an engineering-scale test on the cesium-removal ion-exchange resin in support of the Hanford Waste Treatment Plant (WTP). The tests were conducted at the SRNL Engineering Development Laboratory using actual resin (c-inset) and nonradioactive simulants of the Hanford waste.

(d) Duane Adamson of SRNL observes the foaming behavior of a vacuum evaporator under test at the SRNL Engineering Development Laboratory in support of the Hanford



Waste Treatment Plant (WTP). The engineering-scale evaporator is a full-height and 1/9-scale diameter replica of the plant equipment with clear plastic walls to permit observation of the liquid-gas interface. SRNL has used its extensive experience in the treatment of SRS high-level nuclear waste and the development of the Defense Waste Processing Facility (DWPF) to assist the Hanford site over the past 10 years in the development of the WTP for treatment of their high-level waste. Zafar Qureshi (d-inset) of SRNL operates the controls and monitors the performance of the vacuum evaporator.



FBI Opens Laboratory Suite at SRNL

In November 2006, the Federal Bureau of Investigation (FBI) and SRNL opened a new laboratory and office suite for the forensic examination of radiological material and associated evidence, located at SRNL.


The new Radiological Evidence Analysis Lab Suite (REALS) will serve as a hub laboratory for the FBI and intelligence agencies that are involved in the prevention of terrorism and the investigation of the dispersal of radiological materials. The new REALS provides the FBI with a flexible radiological containment laboratory where FBI experts can safely conduct forensic examinations on items of evidence associated with radiological material. The REALS represents a significant forensic partnership between the FBI and SRNL, said Dr. Joseph DiZinno, FBI Laboratory Director.

The FBI and SRNL have a long-standing partnership to provide law enforcement with the ability to conduct investigations that involve radioactive materials. "SRNL's mission is putting science to work to support the security of our nation and its people," says Dr. G. Todd Wright, SRNL Laboratory Director. "This significant partnership with the FBI allows us to combine our radiological expertise with the FBI's forensic expertise to provide a new level of support to combat the war on terrorism."

SRNL conducted several years of development to adapt FBI forensic protocols for application in radiological labs. Based upon this research the REALS is equipped with radiological containment systems to protect workers from harmful radiological evidence, while FBI Laboratory examiners perform

traditional forensic examinations on contaminated evidence. For example, this laboratory space will allow an FBI examiner to collect latent prints or DNA which could eliminate or include a suspect associated with a "dirty bomb." SRNL and other Department of Energy laboratories conduct the analysis of the radiological components.

SRNL also provides radiological crime-scene training to FBI agents from around the country who are members of the FBI's Hazardous Materials Response Teams. These agents are trained to safely

collect, preserve, and document evidence from radiological crime scenes. Additionally, SRNL instructors provide training for the FBI Laboratory's Hazardous Evidence Analysis Team (HEAT). The HEAT members are certified by DOE to handle radiological materials at any DOE laboratory. 



(Top) A disposable radiological "dog house" containment was developed for examination of evidence contaminated with low to moderate levels of radiation.

(Bottom) SRNL provides a variety of training for the FBI, including the packaging of radiological evidence.

Storing Hydrogen for the Vehicle of the Future

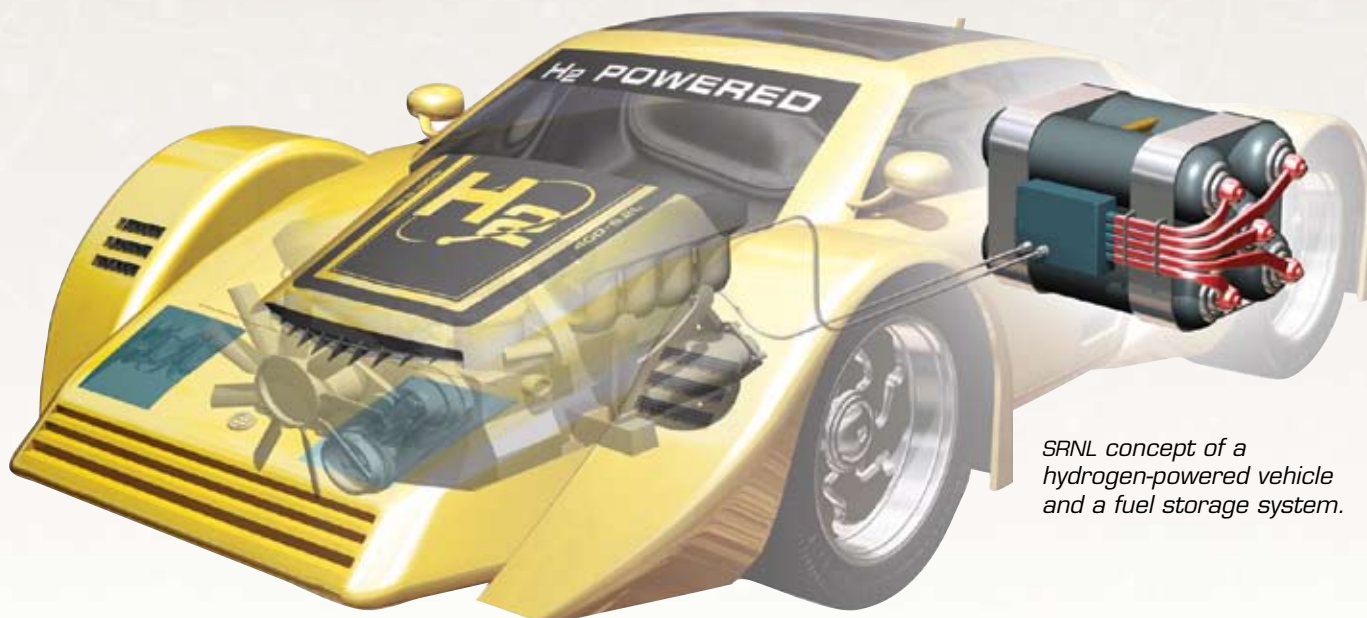
The U.S. has embarked on an ambitious program to develop the technology needed for commercially viable hydrogen-powered vehicles. How to store hydrogen on board a vehicle is one of the key technology challenges that must be addressed to make hydrogen practical for consumer use. SRNL is at the forefront of research and development of solid-state methods of hydrogen storage, which have safety and practicality advantages over storage as a liquid or a gas. SRNL's innovative programs in metal hydrides, complex hydrides, carbon nanotubes, and porous-walled hollow glass microspheres are showing great promise. Automakers such as Toyota and GM are also making use of SRNL's expertise, collaborating with the laboratory on various projects to explore safe, efficient methods of hydrogen storage for vehicle applications.

The promise of a clean energy source that would also end U.S. dependence on foreign oil has been an alluring prospect for many years. In 2003, the administration embarked on a major effort to make hydrogen the fuel of the future for transportation needs. Hydrogen is not only one of the most abundant elements, but it can be burned cleanly, with water vapor as the only residue. To achieve the objective of practical hydrogen-fueled vehicles, many challenging technical breakthroughs will have to be achieved (e.g., economical generation of hydrogen, creation

of a distribution infrastructure, vehicle retooling). One challenge that is being addressed by SRNL is on-board vehicle storage of hydrogen.

An acceptable hydrogen storage system must be lightweight, must hold sufficient hydrogen to give the vehicle a travel range comparable to gasoline-fueled vehicles, must allow rapid and easy fueling, must be affordable, and—above all—must both be safe and be *perceived* as safe.

The most promising hydrogen-storage option for balancing all of these requirements in the long



SRNL concept of a hydrogen-powered vehicle and a fuel storage system.

term is solid-state storage, which has proven to be both safe and efficient. Current hydrogen storage options, such as compressed gas and liquid hydrogen, come close to meeting the targets for energy density, but they fall short when increased energy availability is balanced against safety and cost. Solid-state hydrogen storage materials (especially metal hydrides) have been studied for more than 30 years because of their excellent volumetric hydrogen-storage densities and their inherent safety. Dr. Theodore Motyka, Hydrogen Technology manager at SRNL, notes that hydrogen can be stored at low pressure on solids versus gas or liquid. "Also," he says, "the shape of the fuel tank for solid storage can be very flexible due to the low pressure. And this can better fit the design of the vehicle."

SRNL's extensive and unique expertise in handling and storing hydrogen is based on more than 50 years of technology support for the Savannah River Site (SRS), which is the sole provider of tritium, a radioactive isotope of hydrogen, for the U.S. nuclear defense program. This includes 25 years of developing and deploying solid-state storage systems.

SRNL has also developed, designed, and demonstrated the metal hydride technology behind the largest tritium processing facility in the world, which is located at SRS. The use of metal hydrides for hydrogen storage, separation, and processing significantly reduced the cost and footprint of that facility, while enhancing safety and environmental protection.

In addition to exploring conventional metal hydrides for hydrogen storage, SRNL is also involved in research on promising new materials such as complex hydrides, doped carbon nanotubes, and glass microspheres.

Metal Hydrides

Traditional metal hydrides (powdered or granulated metals that hold hydrogen in an atomic rather than molecular form) work well for stationary or heavy-duty vehicle applications. Because the weight of the hydrogen is low compared to the weight of the metal, such storage systems are heavy, which makes them unsuitable for light-duty vehicle applications. Over the years, many hydrides have been studied, including hydrides of nickel and other transition metals, rare-earth alloys, and related materials. In general, it has been found that only about 2 wt% hydrogen can be stored and released by this class of compounds under conditions that are practical for on-board application ($<100^{\circ}\text{C}$). Much larger quantities of hydrogen (7 wt%) can be found in other simple hydrides such as magnesium hydride (MgH_2), but the temperatures for

hydrogen release are too high (300°C) for practical transportation applications.

This gap between the hydrogen-loading capacity and hydrogen-release temperature for different hydrides is clearly shown in *Figure 1*. The higher-capacity materials have high release temperatures, while the low-release-temperature materials have low capacity. The R&D objective is to find materials that have high capacity at low release temperatures. The Department of Energy (DOE) 2010 target for automobiles is 6 wt% hydrogen on a system basis released at less than 100°C .

Much of the work on metal hydrides is now focused on lighter structures to bind the hydrogen and on lower temperatures to release and reabsorb the gas. Because of the limitations of traditional hydrides, SRNL researcher Dr. Ragaiy Zidan and his colleagues have focused their

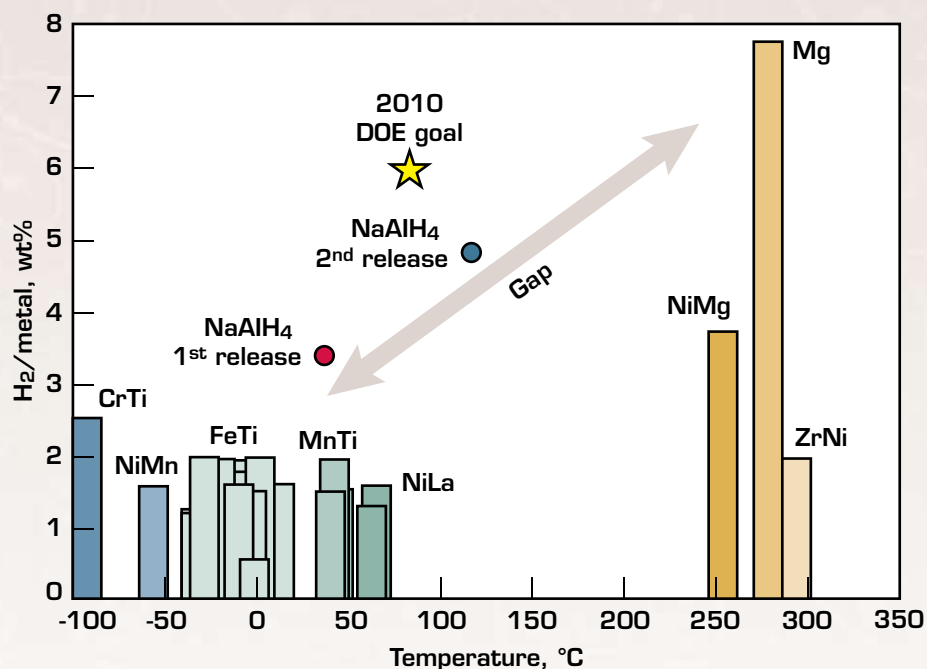
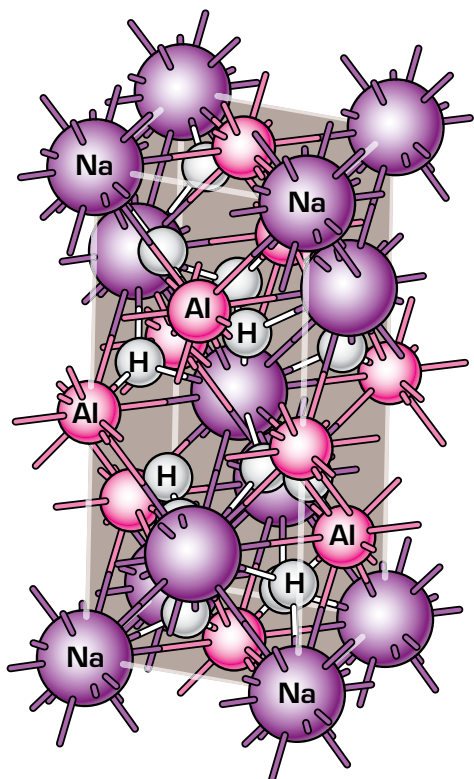


Figure 1. Advanced hydrogen storage materials metal hydride status and future goal. The gap shows the region of greatest research interest; the DOE goal is 6 wt% hydrogen on a system basis by 2010.



attention on promising new higher-capacity materials, such as complex hydrides and carbon nanotube materials.

Complex Hydrides

Complex hydrides differ from conventional inter-metallic hydrides in that they are mixed ionic-covalent compounds. Because complex hydrides involve lightweight metals, such as aluminum, boron, sodium, and magnesium, they show good promise for hydrogen storage. It was once believed that these compounds could be made to release their hydrogen, but could not be made to easily reabsorb hydrogen. It has now been shown that these materials can be made to reabsorb hydrogen under practical conditions by doping them with small amounts

of transition metals such as titanium. SRNL's researchers and others are working to increase the hydrogen capacity and to improve these materials' absorption rates at operating temperatures compatible with vehicle application.

The key advance in the metal-doping work was reported in 1997 by Dr. Borislav Bogdanovic and his team at the Max Planck Institute in Germany. They found that a titanium-doped sodium aluminum hydride (sodium alanate), NaAlH_4 , could reversibly absorb 3.7 wt% hydrogen at reasonable temperatures and an additional 1.8 wt% at higher conditions. This work touched off a number of investigations in search of dopants that would release the full 5.5 wt% of hydrogen held by sodium alanate. The potential role that alanates and similar compounds can play in filling the performance gap described earlier is shown in *Figure 1*, where complex hydrides like sodium alanate are shown starting to fill the gap by exhibiting both high capacity and relatively low release temperatures. The structure of sodium alanate is shown in *Figure 2*.

In one study, SRNL's Dr. Zidan, working with Dr. James Ritter and coworkers from the University of South Carolina, showed that doping sodium alanate with a combination of titanium and graphite resulted in a marked improvement in the overall rate of hydrogen absorption and desorption. Dr. Zidan believes that the graphite helps enable the mobility of aluminum and other species during reabsorption of hydrogen on the material. The role of graphite is, therefore, believed to be different from that of titanium, which is more of a reaction promoter or dopant for the hydrogen reabsorption.

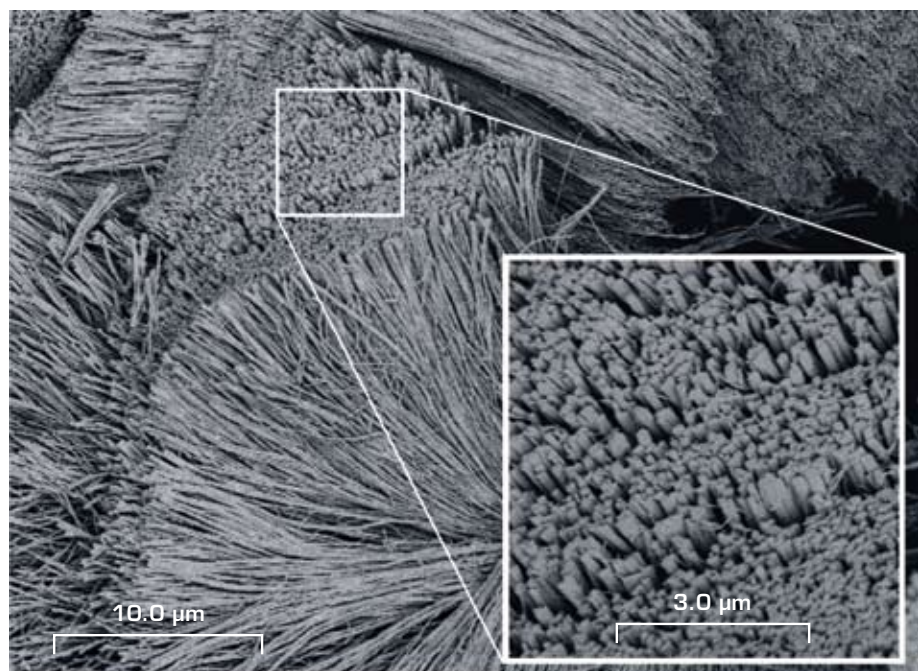


Figure 2 (top). Structure of sodium alanate (NaAlH_4). The material exhibits both high capacity and relatively low release temperatures for hydrogen.

Figure 3 (bottom). Carbon nanotubes. Light weight, high surface area, and ability to be doped with metals offer promise for low-temperature hydrogen storage. [See also Figure 4.]

Dr. Zidan and his team also developed a new patented process—molten-state synthesis—which produces homogeneous new material formulations and further improves the hydrogen evolution kinetics. In this process, components used for preparing hydrides are mixed at near-melting-point temperatures to produce new materials. The team has successfully prepared $\text{Na}_2\text{LiAlH}_6$ and other compounds based on magnesium and magnesium–nickel using this process. While some materials have shown promise, the work is still continuing to synthesize better ones.

Other hydride storage materials that are being investigated are borohydrides such as LiBH_4 (18 wt%) and $\text{Mg}(\text{BH}_4)_2$ (14.9 wt%), nitrides such as Li_3NH_4 (10.4 wt%) and LiNH_2 (8.7 wt%) and mesoporous reduced-metal oxides such as $\text{TiO}_2\text{-C}_{60}$. The most promising appear to be the LiBH_4 materials.

Carbon Nanotubes

Carbon nanotubes are another high-potential hydrogen-storage material. Their light weight, high surface area, and ability to be doped with metals and metal alloys make them attractive materials for this application.

Working with Dr. Apparao Rao at Clemson University and others, SRNL has identified methods of producing large quantities of single- and multi-wall nanotubes. Figure 3 shows some of the nanotubes produced. The long, thin hollow structures are approximately $1/10,000^{\text{th}}$ the width of a human hair (i.e., ~ 10 nm). Methods were then developed for doping the nanotubes with metals and metal alloys. Figure 4 shows the tip of a nanotube with encapsulated metal particles. Testing of these materials showed some hydrogen-storage potential at near room temperatures.

In order to improve the performance of these nanotubes (which currently absorb only about 1 wt%), a better understanding of their physical and chemical properties and their bonding mechanism with hydrogen is needed. DOE is funding work by SRNL and researchers at Virginia Commonwealth University, the Georgia Institute of Technology, and Oak Ridge National Laboratory to study this problem. This project will look at metal-doped carbon nanotubes and will relate their physical and chemical properties to their ability to bond and release hydrogen. Recent theoretical work has shown that hydrogen forms a weak covalent bond with carbon nanotubes at room temperature, which further supports them as a promising material for hydrogen storage.

Porous-walled, Hollow Glass Microspheres

SRNL has combined world-class capabilities in hydrogen and glass science and technology to develop a novel, interdisciplinary

approach to hydrogen storage using a proprietary method of producing porous-walled, hollow glass microspheres (PW-HGMs). The porosity introduced in the wall differentiates the SRNL PW-HGMs

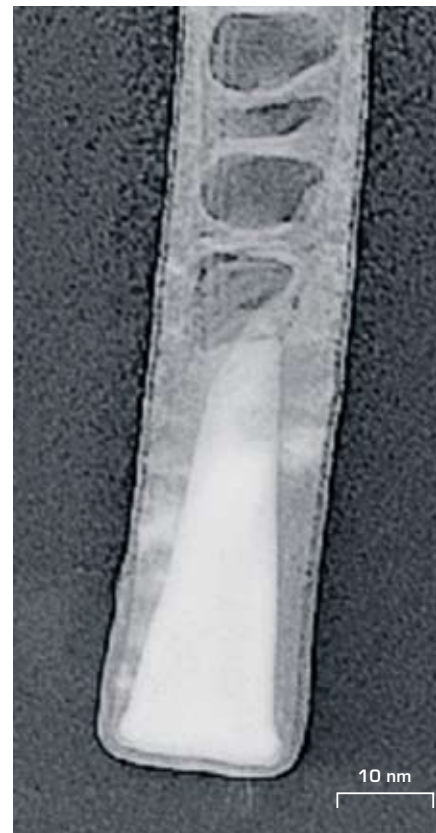


Figure 4 (top). Transmission electron micrograph of a carbon nanotube. The doped region is the light triangular shape shown at the bottom.

SRNL's unclassified hydrogen research and development is housed at the Center for Hydrogen Research (bottom), a state-of-the-art laboratory facility owned by Aiken County and designed to facilitate collaboration. SRNL leases half of the facility; the other half is being leased to private industry, universities or others in hydrogen-related research.

Storing Hydrogen for the Vehicle of the Future

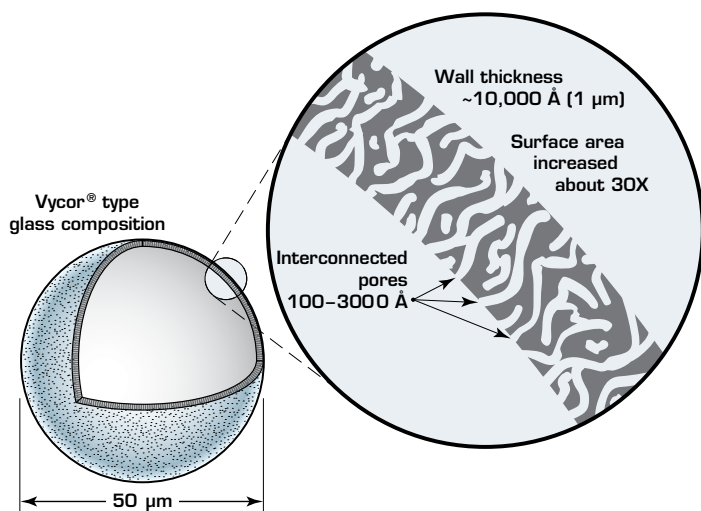
from conventional HGMs used for years in many industrial and commercial applications.

By employing alkali borosilicate glasses that phase-separate, SRNL researchers Dr. Ray Schumacher, Dr. George Wicks, and Dr. Leung Heung were able to produce mi-

crosheres with porous walls of controllable channel size. They used a sodium borosilicate glass in the Vycor® region that is known to phase-separate into two continuous glass phases. One phase is rich in alkali borate and is soluble in acid; the other is near pure silica

and is not soluble. After forming, the PW-HGMs—which are $\sim 50\text{ }\mu\text{m}$ in diameter—are washed in acid to leave an interconnected network of pores $\sim 100\text{--}3000\text{ }\text{\AA}$ in diameter within their walls (*Figure 5*). The channels can subsequently be altered (opened or closed) to varying degrees by a number of techniques to assist in loading of absorbents and in hydrogen loading and unloading operations.

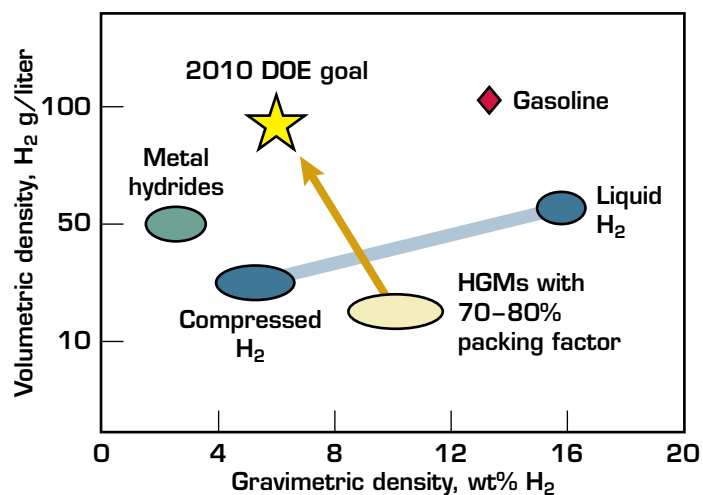
In addition to using relatively high temperatures, other concepts are being investigated for releasing hydrogen from glass forms and structures. One interesting approach developed by Dr. James Shelby from Alfred University uses a doped glass that, when stimulated with IR radiation, gives a large increase in hydrogen diffusion. Alfred University is leading a new joint collaboration involving SRNL and Mo-Sci Corp. to investigate this phenomenon in various glass systems and forms. A comparison of the relative relationships of the different hy-



(top-left to right) Dr. George Wicks, Dr. Leung "Kit" Heung, and Dr. Ray Schumacher display the apparatus and products involved in porous-walled, hollow glass microspheres.

Figure 5 (bottom-left). Schematic of PW-HGM. The surface area of these microspheres is significantly increased by washing in acid baths, which leave pores whose dimensions and behavior can be modified to improve hydrogen storage capability.

Figure 6 (bottom-right). Direct storage in HGMs. Chart shows the relative relations of the various automotive fuels, compared to the DOE system goal.



drogen storage approaches on a gravimetric and volumetric basis is shown in Figure 6.

The porosity of the PW-HGMS can be controlled to improve hydrogen-cycling operations. Also, the porosity, or subsequent coatings on the walls, can act as filters, which may be important for mixed gas streams and for excluding possible poisons to absorbents inside in PW-HGMS. Several patents involving this new technology have been filed by SRNL researchers.

Engineering

In addition to work on hydrogen storage materials, SRNL is also leading the DOE effort on engineering and engineering systems testing and evaluation for metal hydride hydrogen storage. This effort is carried out under the auspices of the DOE Center of Excellence on Metal Hydrides led by Sandia National Laboratory. The goal of the DOE Center of Excellence program is to develop a 1-kg (approximately 1/5-scale) prototype hydrogen storage system that also meets the DOE automobile-based targets for 2010. The program is a five-year effort that began in 2004. SRNL will be leading the system engineering efforts for the Center. Partnering with other national laboratories and universities, SRNL is working toward delivery of a prototype storage system that meets the DOE Center of Excellence goals for hydrogen storage. ☉

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Technologies in the News

Three SRNL-developed technologies were selected for inclusion in the World's Best Technologies Showcase

(also see pages 17 & 21)

SOLACE — Solid or Liquid Aerosol Contaminant Extractor

The Solid or Liquid Aerosol Contaminant Extractor (SOLACE) is a novel, compact and portable device that collects airborne particles for analysis. The SOLACE, which can operate in hostile environments, has the potential to provide law enforcement agencies with a powerful tool to detect methamphetamine labs and could also collect particles in homeland security applications such as biodefense.



Small enough for handheld operations and having few moving parts, the SOLACE is ideally suited for reliable performance while using limited power. Four C-cell batteries provide eight hours of operation. A second, even more compact, unit, uses only six AA batteries for eight hours of operation. Samples, including toxic or radioactive particles, are collected electrostatically on a solid substrate or into a liquid.

A U.S. patent application has been filed on the invention.

Washington Savannah River Company (WSRC) invites interested companies with proven capabilities in this area of expertise to enter into a licensing agreement with WSRC to manufacture and market this and selected other devices as commercial products.

Interested companies should contact Steve Wach at:
803.725.3020
steve.wach@srnl.doe.gov

WBT showcase
WORLD'S BEST TECHNOLOGIES

Tailoring Inorganic Sorbents for Strontium and Actinides

A national team led by SRNL has tailored a new material to improve the removal of strontium and actinides from nuclear-waste salt solutions, a step that will facilitate the immobilization of these solutions for safe disposal. Transmission electron microscopy and x-ray absorption fine structure were used to understand the mechanisms used by monosodium titanate (MST – a commonly used sorbent) to sorb actinides, enabling the team to modify the sorbent to improve performance. They found that treating MST with hydrogen peroxide increased the crystalline fibrous fringe area around the particles that is associated with the sorption process. As a result of the improvement, the process can use one-fourth the amount of sorbent and still increase throughput three-fold.

How do you go about tailoring a sorbent to preferentially remove specific elements from a complex chemical mixture? The question is highly relevant to

waste management and environmental remediation work at the Savannah River Site (SRS); successful development of new technology would benefit similar sites throughout the DOE community.

One approach, used by a national team led by Dr. David Hobbs of SRNL, is to first understand the science that leads to the preferential sorption of an element by a sorbent. Then that science can be put to work by structurally modifying the sorbent to increase the number and availability of these sorption sites. Dr. Hobbs, Dr. May Nyman of Sandia National Laboratory, Dr. Abraham Clearfield of Texas A&M University, and Dr. Edward Maginn of the University of Notre Dame took on the challenge of modifying titanate compounds used for separating strontium and actinides from the “witches’ brew” of nuclear-waste salt solutions.

Earlier work had shown that titanium-based materials, and specifically monosodium titanate (MST), were excellent sorbents for strontium and actinides in



Dr. David Hobbs with bench-top test apparatus for sorbent tailoring.

strongly alkaline and high-sodium-containing salt solutions. In order to better understand the mechanism of uptake of strontium and actinides by titanate sorbents, studies led by SRNL's Dr. Martine C. Duff used the techniques of transmission electron microscopy (TEM) and x-ray absorption spectroscopy.

To better understand the physical nature of the MST and that relationship to its sorbent capabilities, TEM was used with the help of Dr. John P. Bradley, formerly of Georgia Institute of Technology and now with Lawrence Livermore National Laboratory. *Figure 1* shows low- and high-magnification micrographs of a sectioned MST particle. The pictures show an amorphous inner structure and a crystalline fibrous fringe area with high surface area. With the help of the TEM, selective-area electron diffraction was used to detect the presence or absence of crystallinity and is shown in the small inset pictures. With the use of energy-dispersive spectroscopy—another feature of the TEM—the team was also able to determine that strontium preferentially sorbs to the outer fringe material, but was unable to determine the actinide preference. This information was vital because it

showed that if Dr. Hobbs and his team were able to increase that outer fringe area through product synthesis or treatment of the product, they could potentially improve the performance properties of the sorbent.

Dr. Duff used x-ray absorption spectroscopy to look at the sorption/ion exchange interactions at the molecular level. By studying the fine structure oscillations past the x-ray absorption edge, average local structural information can be revealed about the metal-ion and sorbent interactions. This technique is known as x-ray absorption fine structure (XAFS) spectroscopy. *Figure 2* shows an x-ray absorption edge with its fine structure. Simplistically, the absorption-edge energy is characteristic for the particular atom, the frequency of oscillations is indicative of the distance between atoms, and the amplitude of oscillations

indicative of the number and types of neighbors. Thus, XAFS can help to differentiate among four possible mechanisms of uptake of the metal by the sorbent surface: incorporation into the surface; outer-sphere sorption, ion exchange, or electrostatic sorption; inner-sphere sorption, specific adsorption, or chemisorption; and surface precipitation or polymerization.

Samples were prepared at SRNL with strontium (Sr), uranium (U), neptunium (Np), and plutonium (Pu) sorbed on MST. They were then examined by Dr. Duff and

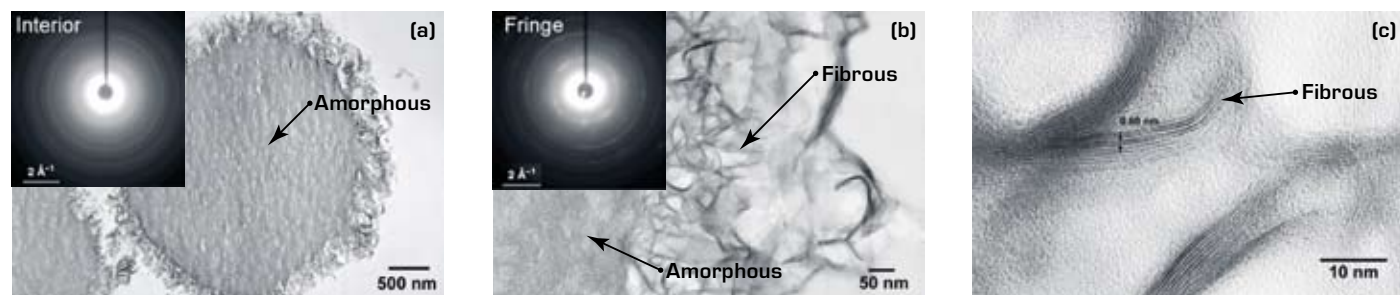
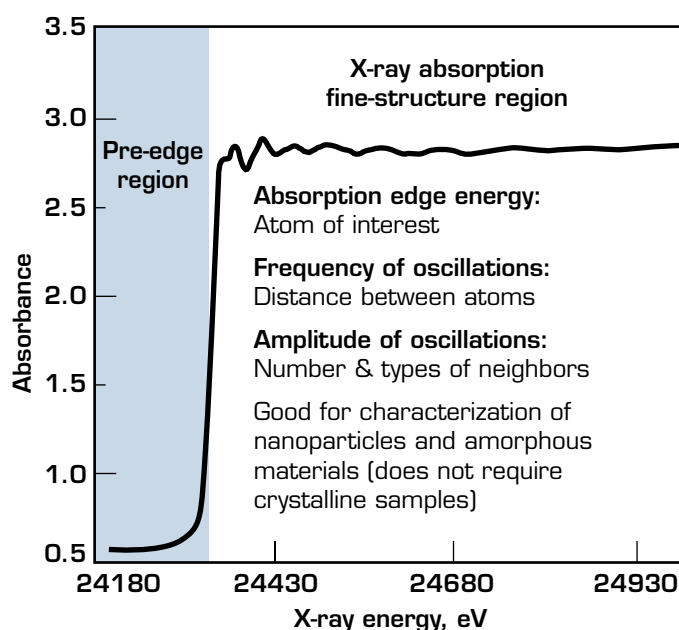


Figure 1 (above). TEM characterization of MST. MST contains an amorphous interior and crystalline fibrous fringe material. Strontium preferentially sorbs to outer fringe material (actinide preference not known). The electron diffraction pattern from the interior is smooth (a-inset), whereas it shows speckling from the fringe (b-inset), indicating crystalline structure that can be exploited to improve sorbent performance.

Figure 2 (top-right). Fine-structure oscillations reveal average local structural information.

Dr. Douglas Hunter (also of SRNL) at the National Synchrotron Light Source at the Brookhaven National Laboratory. The results, shown in *Figures 3 and 4*, clearly revealed the nature of the metal uptake by the sorbent. In the case of strontium, XAFS pointed to an inner-sphere sorption of partially hydrated Sr^{2+} species. In the case of uranium, the mechanism changes, depending on the concentration of uranium on the surface. At low-U concentrations, the mechanism is an inner-sphere sorption as monomeric U(VI)-hydroxo and U(VI)-carbonato on distorted TiO_2 octa-

hedra. At high-U concentrations, the mechanism shifts to dimers of U with the same complexes sorbing on distorted TiO_2 octahedra. The same shift in mechanism with concentration is observed with plutonium on MST. At low concentration, the Pu uptake is an inner-sphere sorption of Pu(IV) on normal TiO_2 octahedra. Even when starting with Pu(VI), the Pu is reduced to Pu(IV). At higher concentrations, a polymeric Pu(IV) is seen sorbed to the surface. This would explain the slow kinetics seen with Pu sorption. Finally, for Np, an inner-sphere sorption of Np

as polymeric Np(V) on distorted TiO_2 octahedra is seen. This work was not only fruitful in elucidating sorption mechanisms, but it also led to advances in the molecular modeling program for XAFS analyses and patent applications for radioactive XAFS sample containment and shielding.

Salt Waste Processing

In 2001, the Department of Energy (DOE) selected MST for the strontium/actinide separation step within the Salt Waste Processing Facility (SWPF) at SRS. Subsequently, MST was selected for use in the Site's Actinide Removal Process (ARP) to treat waste solutions low in cesium activity in a small treatment facility. The proposed SWPF and existing ARP facilities have contact times between the MST and the alkaline waste solutions of around 24 hours. Increased waste-characterization data indicate that alpha-removal characteristics (principally plutonium removal) represent a greater challenge than that for ^{90}Sr removal. Based on recent testing at SRNL, the performance of MST to efficiently and rapidly remove alpha-emitting radionuclides serves as the limiting factor in sizing the equipment and operational throughput. Even higher alpha activities are projected for the SWPF and ARP operations as a result of initiatives to accelerate the disposal of high-level waste (HLW) at SRS. Due to the limited solubility of titanium in HLW borosilicate glass, there are limits on the amount of MST that can be used in SWPF and ARP facilities. Consequently, the need exists for an improved Sr/alpha removal material that exhibits

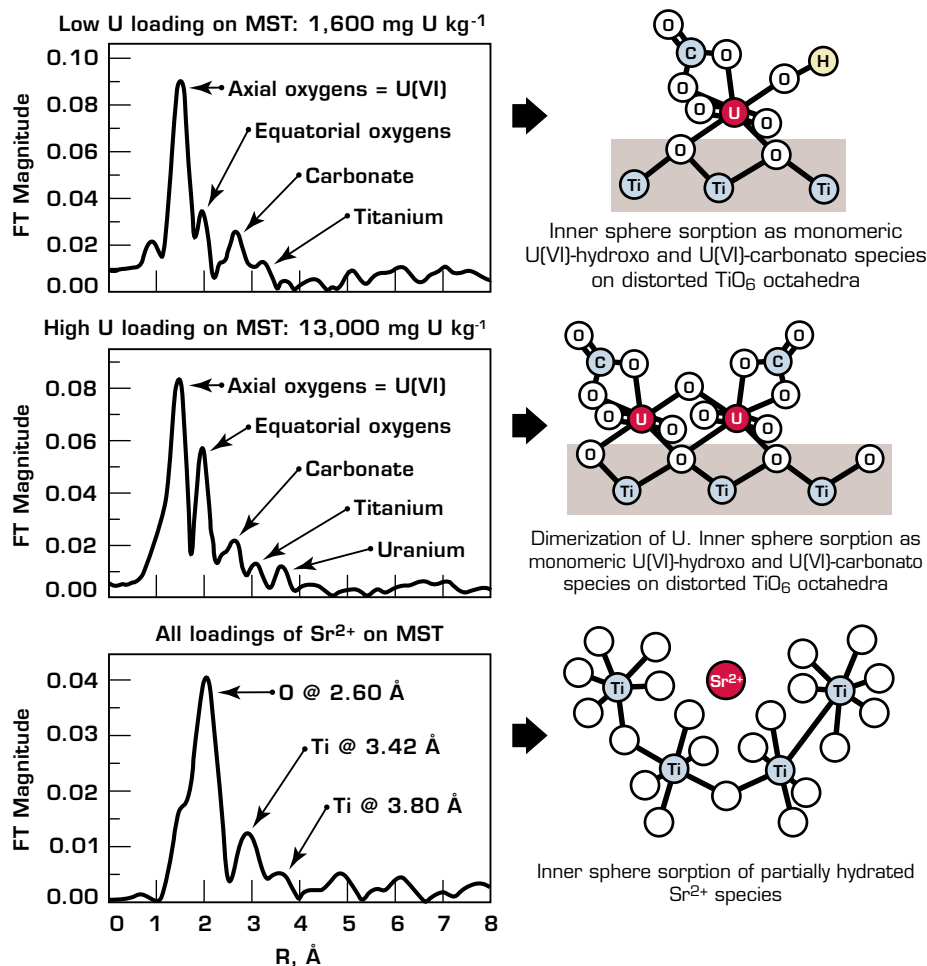


Figure 3. XAFS studies: U(VI) and Sr^{2+} .

increased actinide capacity (reduces sorbent usage) and removal kinetics (reduces contact time).

The initial work looked at three different titanium-based materials, MST, sodium nonatitanate (SNT) $\text{Na}_4\text{Ti}_9\text{O}_{20}$, and a titanosilicate material $\text{M}_3\text{H}(\text{TiO})_4(\text{SiO}_4)_{3.5}\text{H}_2\text{O}$ (TSP), where M = Na or K, that has a crystal structure similar to the mineral-phase pharmacosiderite. SNT and TSP samples synthesized under different conditions showed no improvement over baseline MST. Studies with MST focused on modifying the synthesis conditions to enhance sorption kinetics and capacity. In addition to evaluating templating agents, the project team investigated the use of mineralizing reagents to modify the MST.

Testing showed that the addition of templating agents produced little improvement in MST performance. However, the use of the mineralizing reagent hydrogen peroxide produced an MST material that exhibited increased strontium- and plutonium-removal performance. The focus of the testing then concentrated on the peroxide-modified MST material. Further testing showed that the action of hydrogen peroxide proved beneficial during the synthesis of MST and as a post-synthesis treatment. The changes introduced by the hydrogen peroxide corresponded to the team's understanding of the nature of sorption by MST. The improved form of MST exhibited a higher surface area and smaller pore size. Both of these changes would be expected to significantly increase sorption capacity and kinetics. Furthermore, as evidenced by the transformation of the white baseline MST to a bright yellow color, the modified MST also incorporated peroxide into the MST framework. Together, these changes in the MST yield a material that performs much better than

the baseline MST for the removal of strontium and actinides from strongly alkaline salt solutions.

The excellent strontium- and actinide-removal characteristics exhibited by these modified MST materials should prove to have significant impacts on SWPF and ARP operations. The higher actinide-removal capacities and removal kinetics suggest that these facilities may require less MST and shorter contact times to affect the necessary radiochemical decontamination factors. A conservative esti-

mate is that the MST concentration could be lowered by a factor of 4 (i.e., 0.1 g L^{-1}) and batch contact times reduced to about 4 hours, which could produce as much as a three-fold increase in throughput.

Performance tests with actual waste supernate demonstrated that the modified MST exhibited better strontium- and plutonium-removal performance than that of the baseline MST (Figures 5 and 6). For example, the decontamination factors for the modified MST measured 2.6 times higher for strontium, and

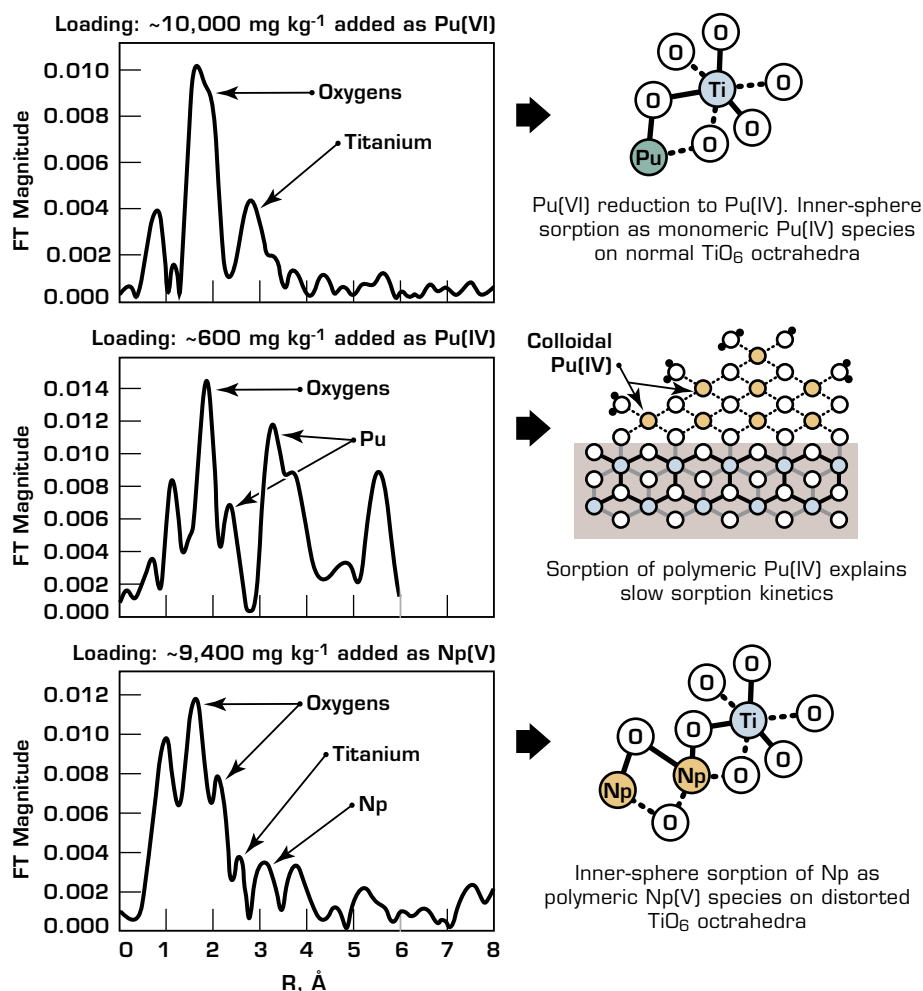


Figure 4. XAFS studies: Np(V) and Pu(IV, VI) sorption to MST.

Disposition of Nuclear Waste

Nuclear waste from the U.S. defense program consists of an insoluble sludge of metal oxides and hydroxides and a soluble fraction of salts, primarily sodium nitrate and hydroxide. This salt solution contains radioactive cesium as the principal radionuclide, as well as traces of strontium and actinides. The Savannah River Site (SRS) plans to treat its salt solution at its new Salt Waste Processing Facility starting in 2011 using solvent extraction to remove the cesium activity and sorption to remove the traces of strontium and actinides. The radioactive components separated will be sent to SRS's Defense Waste Processing Facility for vitrification. The decontaminated salt solution will be sent to SRS's Saltstone facility, where it will be processed and disposed of in a grout form.

between 5.2 and 11 times higher for plutonium, compared to the baseline MST sample.

One of the key questions that had to be answered for the modified MST to be a viable replacement for baseline MST at SRS was the filtration characteristics of the new powder: What was gained in improved throughput by shorter contact times could be lost by slower filtration. Filtration tests led by Dr. Michael Poirier of SRNL showed that the modified MST exhibits filtration characteristics similar to the baseline MST using the same size filter membranes planned for use in the SWPF and ARP facilities.

Currently, the team is working to scale the synthesis of the modified MST to commercial quantities. A custom chemical manufacturer has prepared a 15-kg batch of material that is now being tested for sorption and filtrate performance. Should the commercially-prepared material exhibit improved performance, as expected, the team will continue development of this material for use in the ARP and SWPF.

Next Step: Higher-Performance Sorbents

With this success well in hand, Dr. Hobbs and his team are now looking to improve the performance of other sorbents and to develop new sorbents that can combine removal of several desired elements simultaneously. An example is to combine the MST-removal properties just described with those of a cesium-removal agent such as crystalline silicotitanate (CST).

Dr. Hobbs and his team are also looking beyond nuclear waste for application of their tailored sorbents to specialty separations in the chemical industry and in medicine. Sodium titanates have shown affinity for a wide variety of metal ions in aqueous solutions. Thus, these materials may prove of value in a number of separations. For example, the modified MST may prove to be an excellent material for the

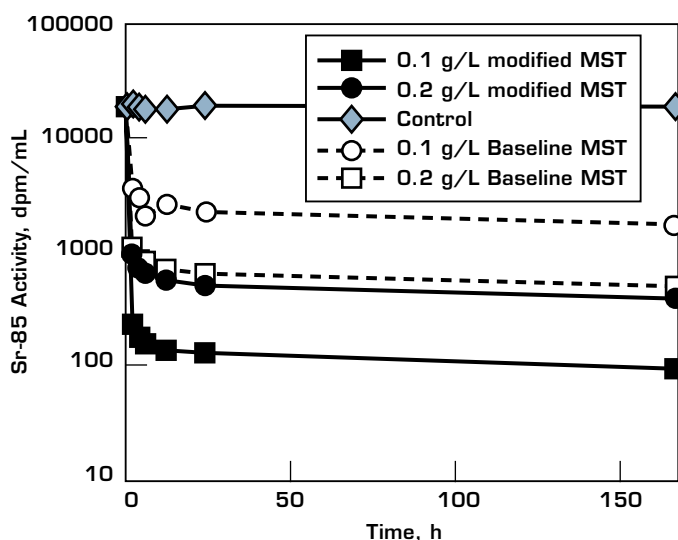


Figure 5. Strontium-removal kinetics for modified and baseline MST samples. The modified MST samples exhibited faster strontium removal kinetics than the baseline MST sample.

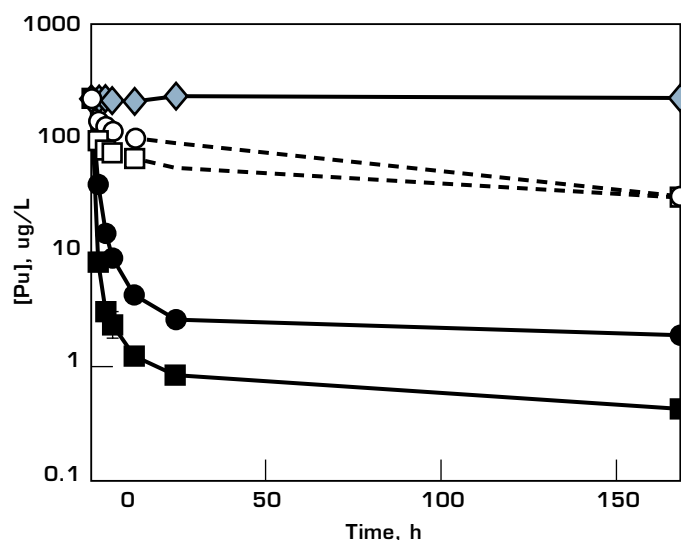


Figure 6. Plutonium-removal kinetics for modified and baseline MST samples. As with strontium, the modified MST samples exhibited much faster plutonium removal compared to the baseline MST.

separation of rubidium-82 from strontium-82, which is widely used for positron emission tomography. By taking advantage of the strong affinity that MST has for strontium but not for rubidium, the modified MST may

prove to be a better separation reagent than the current tin oxide material that is used.

Dr. Hobbs says, "We hope for many more advances from this research and our national team of collaborators." 🌐

For more information regarding this article, contact:

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Dr. Douglas Hunter (left) and Dr. Martine Duff examine report of sorbent performance. The image on the screen in the background is a detail of Figure 1b.

Technologies in the News

BioTiger™ Novel Biocatalyst

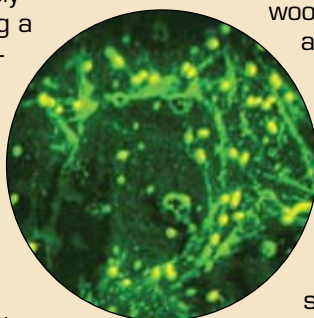
The BioTiger™ biocatalyst cleans up severely contaminated petroleum-polluted sites using a proprietary and carefully balanced combination of bacteria that are especially suited to the task of destroying or otherwise mitigating complex petrochemicals and heavy metals, even under extremely harsh conditions. The biocatalyst was isolated from a century-old oil refinery in Poland, a location with over a century of exposure to extreme environmental conditions, petroleum hydrocarbons, heavy metals, and associated solvents.

The novel microbial consortia produces surfactants that increase the solubility of polycyclic aromatic hydrocarbons (PAHs) and increase access of the bacteria to the

PAHs, thereby increasing the efficiency of the bioremediation. PAHs are widespread pollutants particularly found in association with oil refineries, petroleum storage locations, and petroleum spill sites. Other locations with PAH contamination include energy production facilities, wood treatment locations, harbors, municipal and commercial waste disposal sites, and military installations. By use of microbes to accelerate remediation, treatment time for petroleum-contaminated soil can be reduced to as little as 90 days.

BioTiger™ also has surfactant properties useful in the removal of metals from contaminated soil and substrates. The resulting removed metals, contained within the biosurfactant micelles, are then more easily separated and concentrated for efficient disposal.

A U.S. patent application has been filed on the biocatalyst and method.



Next-Generation Hydrogen Isotope Separation Process

SRNL invented the Thermal Cycling Absorption Process (TCAP) for hydrogen isotope separation in 1980 for the National Security Program. This process plays a crucial role in the production of tritium, the hydrogen isotope that provides fusion energy for our nation's nuclear weapons. Now SRNL's researchers have developed the next-generation TCAP, called Compact Thermal Cycling. This new process greatly simplifies the overall system, increases production, and provides greater flexibility. The process has been successfully demonstrated on a laboratory scale and is scheduled for a large-scale demonstration by mid-2007.

Isotope separation technology is required to separate the distinct masses of a given element, allowing one to take advantage of the differing properties of the various isotopes. In the case of hydrogen there are three isotopes:

tritium, deuterium and protium, of atomic mass three, two and one, respectively. While the fusion of protium with itself and with other nuclides are important reactions releasing the energy powering our sun, the fusion of tritium with deuterium can be achieved at lower temperature and with lesser confinement requirements. Consequently, the use of tritium and deuterium makes the achievement of fusion and its energy release more practical here on earth. The practical separation of pure hydrogen isotopes is, therefore, an essential capability to support modern nuclear weapons and to provide fuel for the realization of fusion power reactors in the future.

SRNL made an important contribution to the field of hydrogen isotope separation with the development of the Thermal Cycling Absorption Process (TCAP), which was invented by Dr. Myung Lee of SRNL in 1980. After development by SRNL researchers in the 1980s, a TCAP isotope separator was installed at the Savannah River Site (SRS) in the H-Area New Manufacturing Facility, a new reservoir-loading and unloading facility. SRS has been the sole provider of tritium, a radioactive isotope of hydrogen, for the U.S. nuclear defense program for over 50 years. SRNL has been a key provider of hydrogen R&D for SRS and Defense Programs throughout that period.

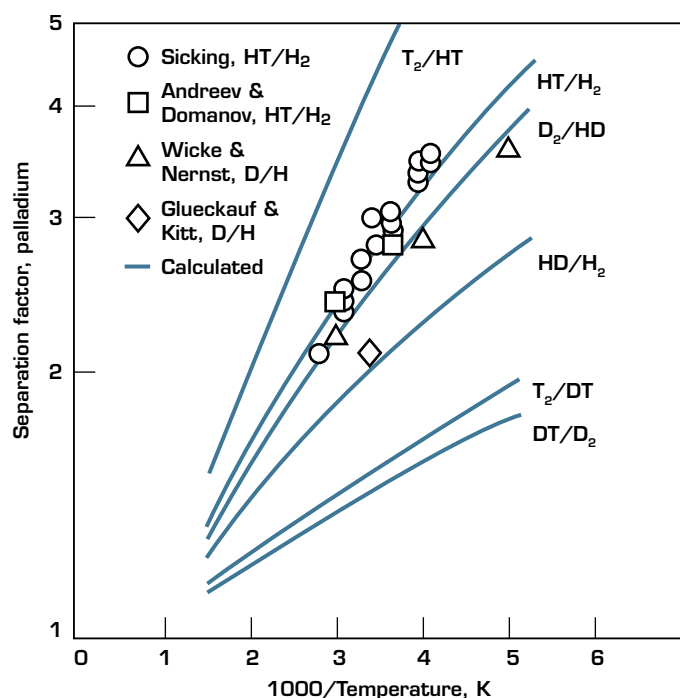


Figure 1. Separation factors for isotopes of hydrogen on palladium.

Hydrogen isotopes have been separated at SRS by thermal diffusion (1955–1986), fractional absorption (1964–1968), and cryogenic distillation (1967–2004). The advantages of TCAP over other methods are its compact size (fits in a glovebox), its small tritium inventory (lower risk), its simple control logic, and its near-ambient operating temperatures.

TCAP has been successfully operating at SRS since 1994. Since that time, a number of improvements to the overall TCAP system have been developed. Dr. Leung Heung of SRNL and his team have recently developed and added a new concept to the equipment needed for TCAP's thermal cycling equipment called Compact Thermal Cycling or CTC (see photo, this page). This concept greatly simplifies the overall system, increases production, and provides greater flexibility. CTC has been successfully demonstrated in the laboratory, and testing of a full-length column to demonstrate protium and deuterium separation is scheduled by mid-2007. This next-generation design will be ready for plant installation after that demonstration.

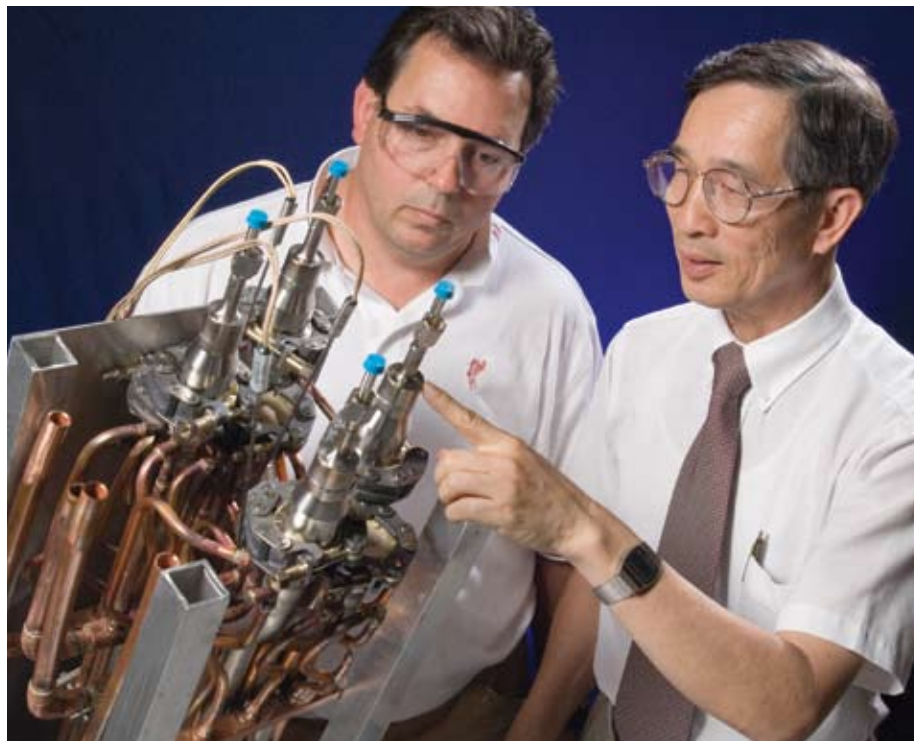
The TCAP Principle

In order to fully appreciate the improvements in the new design, it is important to understand the principle and design of the original, elegant TCAP invention.

The principle for TCAP is based on the difference in absorption of hydrogen isotopes on palladium. This metal preferentially absorbs the lighter isotopes (deuterium and/or protium) compared to the heavier isotope (tritium). This difference is significantly larger at lower temperatures (*Figure 1*). Palladium is placed in a column and the temperature is cycled to separate the isotopes chromatographically (*Figure 2(a)*). The ratio of the

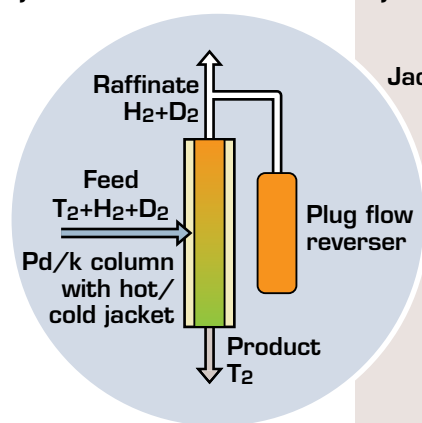
gas-phase isotopic ratio to the solid-phase isotopic ratio is the "separation factor" (also shown in *Figure 1*).

To achieve the best separation, TCAP uses palladium deposited on kieselguhr (Pd/k) as the actual column packing material.

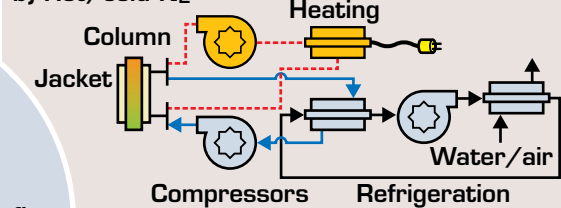


Principal Investigator Dr. Leung "Kit" Heung (right) and Steven Rikard discuss gas-line fittings on the prototype Compact Thermal Cycling column scheduled to demonstrate isotope separation by 2007. Rikard and his crew in the SRNL development machine shop constructed the column.

a) Process schematic



b) Hot/cold N₂



c) CTC

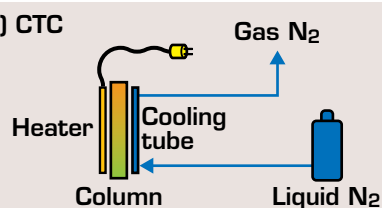


Figure 2. Thermal Cycling: (a) Process schematic. (b) Original TCAP design. (c) New Compact Thermal Cycle design.

Next-Generation Hydrogen Isotope Separation Process

Kieselguhr is a diatomaceous earth with a large surface area. The particle size is 425–600 μm , which allows for high gas-flow rates. Palladium is deposited on its surface by adding a palladium salt solution and then reducing it with hydrogen to the metal. This provides a high Pd surface area for absorption at low pressure drops.

The basic TCAP unit consists of two columns connected end-to-end (Figure 2(a)). One column is filled with Pd/k and does the actual separation; the other is filled with inert kieselguhr and acts as a plug flow reverser (PFR). The PFR is a 12.7-cm-diameter stainless steel column that allows gas transfer to and from the Pd/k separator column with minimal gas mixing.

The Pd/k column is a long stainless steel coil (2.54-cm-diameter) contained within a stainless steel shell. The column is heated or cooled by passing hot or cold nitrogen gas through the shell to heat and cool the Pd/k to separate the isotopes. The gas mixture (deuterium and tritium) is fed to the center of the column, and the raffinate (deuterium) is withdrawn from the top and the product (tritium) is withdrawn from the bottom.

There are two basic modes of operation for TCAP: Reflux (start-up or maintain) and on-line (semi-continuous production). In the reflux mode, the gas is continually cycled between the Pd/k column and the PFR to develop or maintain an isotopic concentration gradient. In the on-line mode, an

isotope (less strongly absorbed) moves farther down the column. The column is then heated, and when the set-point is reached, the PFR is opened and the gas travels from the higher-pressure column to the lower-pressure PFR (Figure 3). While this somewhat reverses the isotopic separation established during the cooling cycle, the isotopic effect is much less at the high temperature, so less separation ensues. The net effect is an overall enrichment in product at the bottom of the column. This cycle is repeated multiple times to produce high-purity product and raffinate.

In the on-line (or semi-continuous production) mode, product and raffinate are removed from the top and bottom of the Pd/k column during the heating half cycle in amounts equal to the feed supplied to mid-column during the cooling half-cycle. This maintains a constant inventory and column profile. Smaller withdrawals will increase the purity of the product and raffinate but reduce the production rate.

Adequate heat transfer is an essential requirement for efficient TCAP performance. When three larger TCAP units (two times the column diameter) were installed in the plant in 2003, special aluminum foam was first placed inside the column and the Pd/k packed in the interstices. This greatly improved the heat transfer inside the column compared to Pd/k alone.

The design of the heating/cooling system for TCAP is a forced fluid circulation system. It is quite large and is comprised of compressors/pumps, several heat exchangers, and piping (Figure 2(b)). The fluid is hot and cold nitrogen gas, although liquids such as perfluorocarbons and ethylene glycol have also been successfully tested.

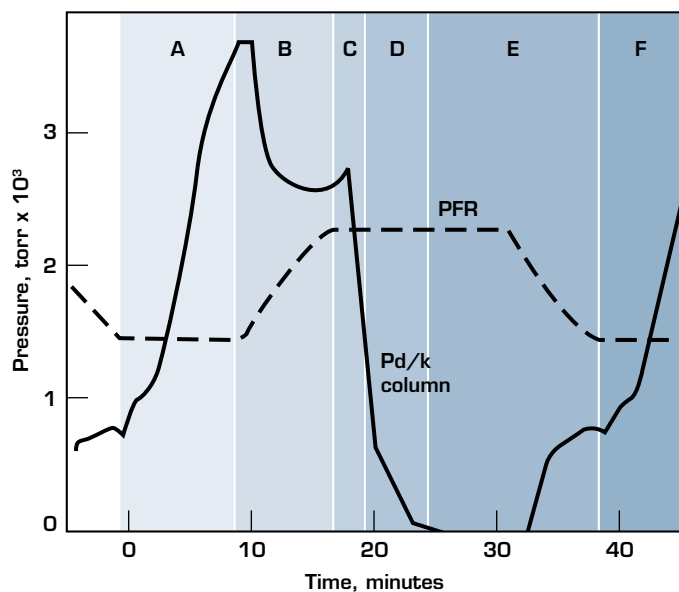


Figure 3. Sequence of TCAP operation in isotope separation:

- A: Start heating column and fill product and raffinate calibrated volumes
- B: Transfer gas from column to PFR
- C: Take mid-point sample and start cooling column.
- D: Feed column
- E: Continue to cool column and transfer gas from PFR to column
- F: Back to A

isotope mixture is fed to the column, and product and raffinate are periodically removed.

In the reflux mode, the column is first cooled, which lowers the pressure relative to the PFR. Gas is then transferred from the PFR to the column. The gas at low temperature isotopically separates with the lighter gas (more strongly absorbed), staying closer to the entrance to the column, while the heavier

One of the first simplifications evaluated for the heating and cooling system was an Induced Natural Convection (INC) process. This eliminated some of the equipment but still required heat exchangers. However, INC was quickly supplanted by the more powerful CTC concept, which replaces the entire heat exchanger system with heating wires and cooling tubes placed directly in contact with the Pd/k column.

Compact Thermal Cycling (CTC)

The CTC design is shown in *Figure 2(c)*. It consists of four Pd/k columns in the shape of “U” tubes connected in series. There are four electrically heated wires on the outside of the column as well as four tubes for a once-through flow of cold nitrogen. The nitrogen is fed as a liquid but is in a two-phase (gas/liquid) form when cooling the column. A comparison of the two designs shows the significant simplification of the CTC design. The new design also promises increased production and greater flexibility.

The original TCAP has been operating extremely well for over 12 years, producing product and raffinate in excess of 99% and meeting all production needs. This next-generation TCAP design is another step forward in performance that will keep SRNL in a leadership role in hydrogen isotopic separation and in the general area of hydrogen technology. 🌐

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Technologies in the News

RadRope™

The RadRope™ portable nuclear material detection system was chosen as one of the top 25 technologies featured at the World's Best Technologies Showcase.



This lightweight, portable system can rapidly detect the presence of nuclear materials in sealed containers on board a ship. Using sensors arrayed in a rope and encased in fabric, the RadRope system can be dangled in the 2- to 4-inch gap between stacked shipping contain-

ers on a cargo ship by a customs inspector. As the inspector walks along the top containers, a hand-held PDA shows an alarm when any sensor in the array detects radiation levels above background radiation, and indicates where in the stack of containers the radiation was detected.

Over 95% of non-North American trade enters the country through U.S. seaports, and these seaports handle over \$750 billion and 2 billion tons of domestic and international freight annually. The RadRope will add another line of defense in the multilayered strategy to prevent the introduction of nuclear and radiological materials into this country.

The sensor nodes are made up of Geiger-Muller tubes, which can be configured to detect both gamma and neutron radiation. Many sensor nodes can be strung together in any length.

The device can be easily used by one person with minimal training. In addition to dangling the device between stacked containers, it can be configured in other ways, such as mounting it on a frame through which items of interest are passed.

Nuclear Materials Detection Technologies, Inc., plans to manufacture and market the RadRope™ device under an exclusive commercial license agreement with WSRC.

A U.S. patent application has been filed on this invention.

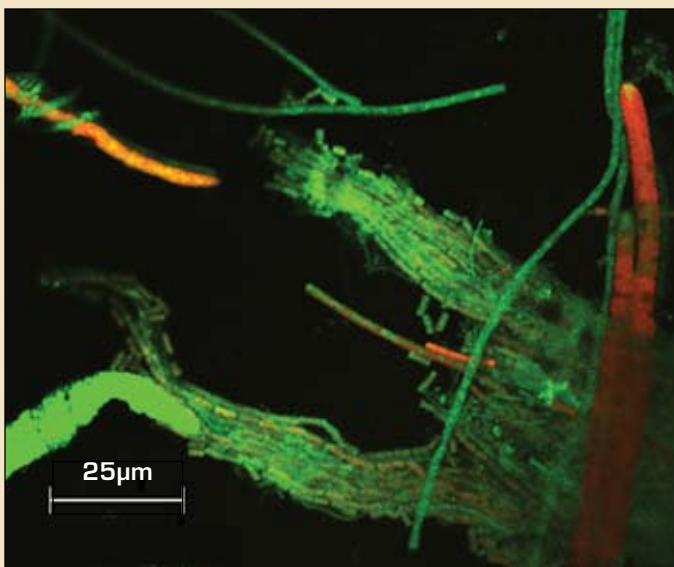
SRNL Passive Remediation Technique Cleans Water Contaminated by Mine Drainage

SRNL has enlarged its toolbox of environmental cleanup methods with the addition of a bioremediation technique to remediate wastewater and groundwater contaminated with mine drainage, nitrates/nitrites, redox sensitive metals and radionuclides, and chlorinated solvents. The passive technique, which was patented in 2006, is long lasting, requires infrequent attention, is stable and requires intermittent addition of inexpensive, readily available, easy to handle biochemical energy sources.



The concept was developed during a study conducted to support remediation of the Savannah River Site's D-Area Coal Pile Runoff Basin. The inventors are SRNL's Mark Phifer, Margaret Millings, Dr. Charles Turick, and Pam McKinsey; and Frank Sappington, formerly of SRNL.

The technique uses bacteria that developed naturally at the contaminated site, selected bacteria from a similar site, or organisms cultured in a laboratory, to establish a community of naturally selected bacteria within the treatment zone. Relatively inexpensive biodegradable oils and waxes provide the electron donors or nutrients for the bacteria. The oils float as a separate phase on the water being treated and degrade slowly to provide a steady nutritional source for the bacteria. In contrast to other types of bioreactors, a bioreactor that uses a floating, separate phase electron donor/carbon source is not subject to deactivation, plugging, and hydraulic failure; it is easily contained within the reaction zone and is not easily flushed out. Contaminant removal will occur by either direct reduction, when that particular contaminant is chemically reduced by bacteria, or by indirect reduction when a reactive end-product of anaerobic respiration reacts chemically with a contaminant to produce an insoluble mineral.



In developing its environmental remediation technologies, SRNL takes care to match the aggressiveness of the treatment to the risk posed by the contaminant and the intractability of the problem. Emphasis is placed on techniques that cause minimum disruption to the existing environment and use little or no external power. When possible, the techniques make use of nature's own cleanup tools, such as naturally occurring bacteria, plants, sunlight, and natural gradients. 🌐

D Area Coal Pile Runoff Basin (top).

Sulfate-reducing bacteria (SRB) used in environmental remediation (bottom).

Awards

MilliWave Thermal Analyzer Wins R&D 100 Award

Researchers at the Savannah River National Laboratory, along with team members from the Massachusetts Institute of Technology and the Pacific Northwest National Laboratory, were named winners of an R&D 100 Award for their invention, the MilliWave Thermal Analyzer. The R&D 100 awards, considered the “Oscars of research and development,” are presented each year by R&D Magazine to the 100 most technologically significant inventions of the year.

The MilliWave Thermal Analyzer, developed by SRNL’s Dr. Gene Daniel and Don Miller and their colleagues, uses millimeter-wave electromagnetic radiation for noncontact, real-time measurements of temperature, amount of energy emitted, and physical changes of materials under extreme temperatures or corrosive environments.

This is the second R&D 100 Award received by the team for a development that resulted from a single long-term research project. In 2001, Dr. Gene Daniel and Bond Calloway of SRNL and their colleagues received the award for the MilliWave Viscometer, which uses similar technology to measure the viscosity of high-temperature fluids under harsh conditions. This research project has been funded by the U.S. Department of Energy Office of Science/Environmental Management’s Science Program for eight years so far. The project focuses on enhancing operations at Savannah River Site and the Hanford Site to convert highly radioactive waste to a stable glass form, but the two inventions also have wide applicability in industrial uses.

According to the inventors, the MilliWave Thermal Analyzer is currently the only thermal-characterization technology that can monitor the properties of materials in the extreme conditions inside a glass melter or process reactor. The instrument does not need to make contact with the materials being analyzed, meaning that it can monitor these properties while the process is running, rather than periodically taking samples of the material out of the process for analysis.

For 44 years, the R&D 100 Awards program has recognized the developers of the top 100 technologically significant products introduced into the marketplace over the past year. Many of the winning products accomplish tasks which no previous product was able to perform. In years past, the R&D 100 Awards have recognized many winning products that later became household names, including the flashcube (1965), the automated teller machine — ATM (1973), the liquid crystal display — LCD (1980), the laser printer (1986), the NicoDerm® antismoking patch (1992), and high-definition television — HDTV (1998). ☉



Dr. Gene Daniel



Don Miller

Awards



Dr. Brian B. Looney

was honored as the Fred C. Davison Distinguished Scientist of the Year Award for 2006 by the Citizens for Nuclear Technology Awareness (CNTA). He is recognized nationally and internationally for his technical expertise, leadership, and scientific contributions in environmental remediation, site characterization, contaminant geochemistry, and modeling. He is a leader in natural forces and processes for environmental cleanup to minimize environmental disruptions.

Dr. Ragaiy Zidan

was honored as the second runner-up for the Herbert C. Brown Innovation Research Award, presented at Purdue University's first Energy Center Hydrogen Initiative Symposium. Dr. Zidan was honored for his innovative methods in hydrogen storage and for extending the work of Dr. Borislav Bogdonovic (the first-place winner) in a way that brought the study of complex metal hydride materials to the forefront of the scientific community.

Dr. Elliot Clark

was selected as a Fellow of the ASM International, the society for materials engineers and scientists. He was recognized for significant contributions to the basic and applied sciences concerning the behavior of hydrogen on alloys, and contributions to leadership roles in the national societies, ASM and IMS.

Joe Cordaro, John McIntosh, Gregory Dyches, Bill Daugherty, & Kevin Tietze

were awarded the National Nuclear Security Administration (NNSA), Defense Programs, Award of Excellence as part of the laser marking team. The team developed, qualified and implemented laser marking equipment and techniques for tritium loaded reservoirs.

Dr. David Peeler

was selected as a Fellow of the American Ceramic Society (ACerS). He was recognized for his outstanding contributions to ceramic science and technology with his work in improving the immobilization of high-level waste in glass for the Defense Waste Processing Facility, immobilization of plutonium and americium/curium in ceramics and glass, and his leadership roles in ACerS.

Dr. Alfred J. Garrett

received the Don Orth Award of Merit for 2006 from WSRC. He is a nationally recognized remote thermal infrared expert. He developed a thermal analysis code that is widely recognized and utilized by U.S. Federal Agencies, universities, and commercial power companies for national security, research, and operational assessment.



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